

## **A. Cover Page**

**Title:** *Evaluation of Biochar for On-Farm Soil Management in California*

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### **CDFA Funding Request Amount/Other Funding**

**FREP Budget request:** Year 1: \$107,636; year 2: \$93,393; year 3: 98,971; Total: \$300,000

#### **Extra-mural or in-kind sources:**

1) Dr. Parikh: 4% time in Y1-Y3, \$11,748 salary and \$4,476 benefits; 2) Placer County Air Pollution Control District, Erik White: biomass for biochar, 60 hours of staff labor (\$6,000 value), and \$5,000 cash; 3) Cool Planet, Drew Jackson: \$30,000 donation for Y1-Y3, with possible additional funds to extend Y4-Y5 and 500 kg of untreated and modified chars; 4) Corigin, Mike Woelk: 500 kg of two different pyrolyzed biochars and smaller quantities other biochars. 5) All Power Labs, Tom Price: 500 kg of two different gasified biochars.

### **Agreement Manager**

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## **B. Executive Summary**

### *1. Problem*

The effect of intensive soil management on soil health is diminishing our ability to farm sustainably. Farming practices are needed that promote long-term productivity, efficient use of nutrients and increase available water from soil. For example, the toll of the current drought is projected at \$1.5 billion (2015: \$900 million, 2016: \$600 million) specifically from crop revenue loss, with a total economic impact of \$2.7 billion in 2015 alone. It is thus evident that adjustments in on-farm practices are needed to sustain the agricultural production potential in the state. The magnitude of this problem requires that these changes and adaptation strategies be multifaceted and targeted for specific agricultural systems. In addition to addressing water use and distribution, on-farm management practices directed at improving soil properties and health also have promise for providing benefits in improving water and nutrient use efficiency. The use of biochar, pyrolyzed biomass, is increasingly being suggested as a soil amendment to provide these and other benefits (e.g., soil fertility, C sequestration). Although biochar can provide some nutrients, it is not inherently a fertilizer material. However, its soil incorporation with other nutrient sources has been shown to impact soil nutrient availability. The potential for biochar to impact water and nutrient (e.g., nitrate) retention gives it promise for effective use in targeted on-farm management systems, including mixed agricultural systems (e.g., organic inputs with synthetic fertilizers), for optimal nutrient availability and minimum nutrient leakage. Additional benefits from biochar amendments may also include C sequestration. However, at present, the specific conditions for biochar application have not been adequately matched with appropriate soil types, cropping systems, nutrient management, and application rates for consistent benefits.

The production and use of biochar can provide other benefits through the utilization of unwanted waste biomass, generation of bioenergy, and a mechanism for fertilizer delivery. For example, forest thinning operations as means of wildfire control and management of forest health results in large quantities of biomass, which require disposal. Similarly, substantial unwanted biomass is generated through agricultural activities such as removal of trees from orchards for replanting and processing wastes from vegetables, fruits, and nuts (e.g., plant residues, fruit stones, nut shells). All of these materials can be converted to biochar as a by-product of bioenergy production. At present, co-production of biochar and bioenergy has not been optimized in terms of energy efficiency and biochar quality, but this is an active research area and progress continues to be made. Finally, inoculation of biochar with fertilizers prior to land application has potential to be an effective strategy to enhance nutrient delivery and increase plant available nutrients in soil.

*This proposed project will evaluate the potential for biochar to be used in California agriculture as a strategy to enhance soil-crop nutrient use efficiency, improve soil-water-crop relations, and increase soil carbon storage.* It is hypothesized that biochar amendment in conjunction with appropriate fertilization rates will lead to increased nutrient retention and use efficiency along with improved soil aggregation, and thus increase soil water retention and soil carbon stocks.

### *2. Objectives, Approach, and Evaluation*

The overarching objective is to provide baseline data and information specific to CA regarding the potential for biochar to provide benefits as a soil amendment for increasing nutrient retention, C sequestration and improving drought resilience for agriculture in CA's Central Valley. Specific project objectives are to: 1) characterize biochars produced from locally available biomass (e.g., Placer County); 2) evaluate the impact of biochar amendments on soil water and nutrient

availability and loss (e.g.,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$ ), carbon stocks, and soil aggregation; 3) evaluate soil conditions and biochar parameters, including biochar and fertilization application rates, which are most likely to lead to beneficial outcomes from biochar amendment; and 4) create the California Biochar Initiative as a central point for objective information regarding biochar use in CA agriculture.

The proposed project will utilize a series of field, greenhouse, and lab studies to examine a variety of soil, biochar types, and application rates under management conditions, which represent mixed agricultural systems. Field plots will be established at the UC Davis Campbell Tract (Yolo County) and UC West Side Research and Extension Center (Fresno County) and biochar will be incorporated in combination with synthetic N-P-K fertilizer. Additionally, a robust set of greenhouse trials will be conducted at UC Davis to examine impacts on crop growth, nutrient retention/leaching, and water relations. As biochar feedstock and production parameters will have a significant impact on its performance and outcome as a soil amendment, full characterization and evaluation of the biochars, with different soils, will be conducted. We will work with our cooperators in Placer County to generate biochars from unwanted forestry and orchard biomass wastes, as well as utilize other common and locally available feedstocks. Additionally, biochars from two other producers operating in CA will be included in the study. Biochars pre-reacted with synthetic N-P-K fertilizers will be included in the experimental matrix. Fertilizer rates will be based on soil sample analysis and both low- and high-end of the recommended application rates will be used to evaluate biochar impact on nutrient use efficiency. This project will provide critical baseline data for biochar use in California agriculture.

We will assess the economic and agronomic efficacy of using biochars produced from locally available waste feedstocks to be used for agronomic benefits for CA crops (i.e., tomato, corn, sorghum). Specifically, we will evaluate how biochar alters the soil physical, chemical, and biological properties, and thus, influences nutrient use efficiency and drought resilience through analysis of soil and plant samples. In addition, we will evaluate the cost effectiveness of utilizing biochar in CA agriculture. We will include the costs of biochar production with other on-farm costs, such as fertilizers and water in order to address the economics of using biochar in agricultural systems. Finally, this data will be made available for development of decision support tools for growers considering using biochar. It is anticipated that these decision support tools will provide clear information for growers to make informed choices and may or may not recommend the use of biochar amendments. Ultimately the success of this project will be based on collection of data, which provides clear information on the efficacy for the use of biochar in CA agriculture.

### *3. Audience*

This research will provide much needed information to a growing number of stakeholders in need of CA relevant data to support guidelines and recommendations regarding the use of biochar in CA agriculture. The targeted audience includes growers, fertilizer producers, biochar producers, farm advisors, PCAs, CCAs and a number of state offices and agencies (i.e., OPR, CDFA, ARB, CalEPA, CAL FIRE, Water Resources Control Board). Due to the need for this information from a variety of parties, we have initiated discussions with state agencies and offices that have indicated their interest in research of this type (e.g., OPR, GO-BIZ, CAL FIRE) and we will continue these dialogues for the duration of the project to ensure relevance to the state.

## **C. Justification**

### *1. Problem*

California agriculture is facing increasing pressures to maintain its high production potential while optimizing nutrient utilization and conserving water consumption. However, with the complex landscape of California agriculture there is a growing need for flexibility in approaches and tailoring of management to specific soils, crops, climates and farming systems. This is both a financial and environmental problem and a suite of economically and agriculturally sustainable approaches for on-farm management are thus required. Another problem in California, exasperated by climate change, is overstocked forests, which are fire hazards. Forest thinning provides an opportunity for large amounts of feedstocks to be utilized for biochar production, possibly in conjunction with energy production. Locally sourced biochar soil amendments have potential to improve soil health and provide a variety of benefits (e.g., soil fertility and nutrient use efficiency, soil structure, microbial habitats, carbon sequestration) for agriculture. This proposal will focus on the role that biochar can play for enhancing nutrient and water use efficiency with due consideration of economic constraints in California agriculture.

### *2. FREP Mission and Research Priorities*

The proposed research is well aligned with the CDFA FREP mission “to promote the efficient and environmentally friendly use of fertilizers” as biochar soil amendments have potential to increase nutrient use efficiency and reduce nutrient losses in agricultural systems. Specific to the 2016 CDFA-FREP special request for proposals, the proposed research will address priority number one: The Role of Biochar in Nutrient Management of California Soil-Crop Systems. The use of this charred organic biomass can improve physical, chemical, and biological properties of soil, which in turn impact nutrient availability and transport and impact soil-water dynamics. This research project will elucidate certain underlying conditions for those benefits to be realized so that decision support tools can be generated for crop consultants and growers to make prudent on-farm decisions.

### *3. Impact*

This proposed project will provide the following benefits:

- i. California relevant data regarding the use of biochar in agricultural soils for crop advisers and growers to make informed decisions regarding the use of biochar soil amendments with consideration given to application rates, soil parameters, and fertilizer requirements.
- ii. Recommendations regarding biochar and fertilizer application rates for increased nutrient efficiency and reduced losses in diverse on-farm management systems, including mixed agricultural systems (e.g., organic biochar inputs with synthetic N-P-K fertilizers).
- iii. Assessment of potential for biochar to provide water savings in agricultural soils with biochar applied at agronomically relevant rates.
- iv. Data for the development of decision support tools based on economic, agronomic, and environmental considerations revolving around the use of biochar soil amendments.

### *4. Long-Term Solutions*

The efficacy of biochar application to agricultural soils is dependent on many variables and extrapolation of data is often not possible. It is therefore imperative that robust analysis regarding the application of biochar, from locally sourced feedstocks, be evaluated for California soils and agricultural systems for specific outcomes. Although there is a dearth of information on biochar

use in California, there is a growing biochar industry and, with it, growing interest from growers and state regulators. *This convergence of interest necessitates that deliberate research evaluating relevant conditions for biochar in California be evaluated to determine if prolonged benefits for soil nutrient efficiency, crop productivity, water retention, carbon storage, and overall soil health can be realized.* This research will provide data specific to soil and climate conditions of Yolo and Fresno Counties and develop much needed information for growers and crop consultants to make informed decisions regarding the application of biochar in conjunction with fertilizer use in California agriculture. If data from this set of experiments demonstrates efficacy of biochar it will be a real win-win situation, providing a highly valuable use of waste biomass for agricultural, energy, economic, and environmental benefits.

### 5. Related Research

Although research in the field of biochar is relatively new, it is currently growing at a near exponential rate. The assemblage of data are beginning to show that there can be real efficacy for biochar soil amendments if thoughtful and careful approaches are used for tailored biochars in specific settings for a set of desired outcomes. These outcomes can include increased water holding capacity, increased soil carbon stocks, reduced nutrient leaching, and enhanced microbial activity.

At the core of potential benefits derived from biochar soil amendments is the selection of biochar itself. Biochar source material and pyrolysis temperature affect molecular structure of biochar and therefore lead to different persistence, reactivity as environmental sorbents, and influences on nutrient cycling (Brewer, et al., 2009, Keiluweit, et al., 2010). Examining different biochar source materials and pyrolysis temperatures has shown distinctively different biochar products (Brewer, et al., 2009, Keiluweit, et al., 2010, Mukome and Parikh, 2015, Mukome, et al., 2013, Novak, et al., 2009). Novak et al. (2009) created biochars from peanut hulls, pecan shells, poultry litter, and switchgrass (250 to 700 °C), demonstrating that high temperature pyrolysis led to low biochar yields, higher surface area, higher pH, high ash content, low surface charge, high percent C in the biochar, and increased aromaticity. The C content of biochars can range widely (36-94%; dependent on feedstock), with C content increasing with higher pyrolysis temperatures (Keiluweit, et al., 2010, Novak, et al., 2009). These and other impacts of feedstock and biochar production are highlighted in the UC Davis Biochar Database ([biochar.ucdavis.edu](http://biochar.ucdavis.edu)), which was created and run by Dr. Parikh.

Although biochar is often touted to increase soil fertility, it is not specifically a fertilizing material. While there may be short-term gains from release of nutrients attached to biochar (Atkinson, et al., 2010), it is widely accepted that biochar should be used in conjunction with other nutrient sources in order to improve the availability of plant essential nutrients. When applied to soils, there are numerous studies that demonstrate biochar can enhance nutrient bioavailability and plant uptake (e.g., Glaser, et al., 2002, Jeffery, et al., 2011, Lehmann, et al., 2003). Often times benefits are seen in acidic to neutral pH soils and soils with coarse to medium textures (Jeffery, et al., 2011). Improvement in CEC, increasing soil carbon, enhancing water holding capacity, and impacting soil microbial communities are some of the mechanisms by which biochar is proposed to improve soil health. The mechanisms by which biochar can alter soil nutrient cycling, retention, and use efficiency are the least well understood and thus areas of growing research interest. For example, biochar has been previously proposed as a strategy for reducing leaching of  $\text{NO}_3^-$  from soils with studies showing mixed results. Biochar derived from corn cobs (360 °C) applied to an alkaline soil

slightly reduced  $\text{NO}_3^-$  leaching in the top 1 m (Zhang, et al., 2013). However, in a more comprehensive laboratory study examining the impacts of 13 biochars on nutrient retention in a sandy soil, it was determined that most biochars had little to no sorption of  $\text{NO}_3^-$  or  $\text{PO}_4^{3-}$  but, that, nine biochars did bind  $\text{NH}_4^+$  (Yao, et al., 2012). However, in this study two of the biochars (Brazilian pepperwood [BP], peanut hull [PH] at 600 °C) did significantly reduce  $\text{NO}_3^-$  (BP: 34%, PH: 34%),  $\text{NH}_4^+$  (BP: 35%, PH: 14%), and  $\text{PO}_4^{3-}$  (BP: 21%); but the PH *increased*  $\text{PO}_4^{3-}$  leaching. Soil column studies with biochar produced from pine wood applied to a sandy soil (0.5, 2.5, 10% w/w biochar) greatly reduced  $\text{NO}_3^-$  (26, 42, 96%, respectively) and  $\text{NH}_4^+$  (12, 50, 85%, respectively), but also reduced the exchangeable amounts of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  and raised the pH too high for the higher application rates (Sika and Hardie, 2014). In another column study, researchers evaluated the impact of biochar additions for soils receiving swine manure. Soil column leachates revealed that biochar (*Quercus*, *Carya* spp.; 20 g kg<sup>-1</sup>) reduced total N (11%) and P (69%) (Laird, et al., 2010). Additionally, when biochar (*Pinus radiata*) was used at a very high application rate (102 t ha<sup>-1</sup>) along with biosolids, significant reductions on  $\text{NO}_3^-$  were observed (Knowles, et al., 2011). Fly ash soil amendments (high temperature) have also been shown to be effective in reducing soil nutrient leaching (i.e.,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$ ) (Pathan, et al., 2002). Inconsistent results from the literature on biochar effects on soil nutrient retention make it difficult to determine trends. In a recent review paper, biochar sorption of  $\text{NO}_3^-$  was surmised to occur with biochars produced at temperatures above 600 °C, with variability in retention based on feedstock materials (Clough, et al., 2013). In the same review the retention of  $\text{NH}_4^+$  was determined to depend on feedstock, but not pyrolysis temperature. Due to these wide ranging effects, it is critical that targeted research specific to soil conditions and available biochar feedstock materials is needed.

The addition of biochar to soil is also used as a strategy to increase soil carbon stocks. The conversion of organic biomass to biochar is a way to “lock” the carbon into recalcitrant condensed aromatic rings, with some reactive functional groups (Xu, et al., 2012). This conversion of carbon means storing carbon in soil, which would otherwise be released to the atmosphere as carbon dioxide when the biomass is mineralized by microorganisms. It is important to note that not all biochar C is recalcitrant and that there is a labile fraction which is typically released when the biochar is added to the soil (Atkinson, et al., 2010). Following biochar amendments, there is potential for native soil carbon to bind to biochar particles and thus enhance the native carbon storage in soils. Ongoing research in the Parikh lab has demonstrated the potential for Ponderosa Pine biochar to reduce the leaching of dissolved organic carbon from forest litter layers (manuscript in preparation). In addition biochar particles may help to increase aggregate stabilization, which may also serve as a mechanism for increase soil carbon – potentially also impacting soil water storage and nutrient retention.

The potential for biochar to increase the water-holding capacity of soils is becoming increasingly important as climate change is shifting weather patterns and drought is becoming more common in certain areas. Not surprisingly, it is the course textured soils with relatively low water retention that benefit the most in this regard. For example, in a set of column experiments examining hardwood biochar (500 °C) in sandy loam, the gravimetric water content increased by up 23% relative to the control (Basso, et al., 2013). Another study looking at biochars from hardwood and switchgrass in loamy sand and silt loam soils revealed the most benefit in the course textured soil, with switchgrass increasing water content the most (Novak, et al., 2012). In the silt loam soil the hardwood biochars had no effect on water content, whereas the switchgrass had modest benefits.

Ongoing research in Parikh's lab has shown that while differences in water holding capacity may be difficult to observe in laboratory experiments as long-term effects of biochar in soil may be increased soil aggregation which may in turn be important for soil-water dynamics.

Additions of biochar to soil can also influence microbial populations, initially reducing microbial activity and influencing community dynamics (Spokas and Reicosky, 2009, Steinbeiss, et al., 2009). The specific response of soil microbes to biochar depends on feedstock and degree of pyrolysis (Glaser and Woods, 2004, Pietikäinen, et al., 2000). Cheng et al. (Cheng, et al., 2006) showed that microbial activity had no effect on the surface oxidation of biochar, suggesting abiotic processes as the mechanism of oxidation. Published results regarding microbial mineralization of charcoals are ambiguous, some suggesting that the process can be microbial mediated while others contradict this (Bruun, et al., 2008, Kaal, et al., 2008, Zimmerman, 2010). Liang et al. (2010) used  $^{13}\text{C}$  labeled organic matter and showed a lower C mineralization of added organic matter in biochar rich soils, despite increased microbial biomass, and rapid incorporation of C into physically protected soil fractions. The authors suggest organic matter stabilization was not mediated by microbial activity but by processes such as compartmentalization, aggregation and adsorption. Conversely, other studies reveal bacteria and fungi coating biochar surfaces (Pietikäinen, et al., 2000) and mineralization of biochar in incubations with bacteria (Hamer, et al., 2004).

Increases in microbial biomass and activity with increasing charcoal application to boreal and temperate soils have also been reported (Kolb, et al., 2009, Wardle, et al., 2008). In a related study examining incubations of graphite carbon of varied feedstocks with soil showed lower  $\text{CO}_2$  evolution in sterilized than non-sterilized soil (Shneour, 1966), indicating microbial driven charcoal mineralization. Further evidence for the stimulation of microbial populations in the presence of biochar was provided by Kim et al. (Kim, et al., 2007) who measured 105 more operational taxonomic units in Terra Preta soils compared to nearby forest soils. Their study estimated that bacterial species richness was approximately 25% greater, with increased earthworm activity and soil aggregation in Terra Preta soils. However, impacts on microbial populations could be indirect, perhaps due to the increases in porosity and habitats provided by the biochar. Although not well understood, the impact of biochar on soil microbial populations is very important as it is well established that healthy soils are rich in microbial populations which play a large role in nutrient cycling, carbon storage, and aggregate stability.

#### *6. Contribution to Knowledge Base*

The proposed project will explore the potential benefits from biochar soil amendments as related to fertilizer and water requirements in California agriculture (Yolo and Fresno Counties) while also adding to the larger knowledge base. There has been little research examining the role that biochar plays in soil aggregation, which can have large implications on soil-water and soil-nutrient dynamics. This study will provide unique data, which will be important to researchers, growers, policy makers, and other relevant stakeholder groups. *In particular, the project will determine the types of local biochar and soil combinations which have greatest potential to provide agronomic benefits and investigate the underlying mechanisms to permit extrapolation of the data for refining experimental variables for investigation in other parts of the state and beyond.* To ensure widespread relevance of the proposed research we will seek project guidance and provide updates on our research to the Biochar Research Advisory Group which is organized through the

Governor's Office of Planning and Research (Co-chairs: Amrith Gunasakara, CDFA; Johnny Gonzales, State Water Resource Control Board; Sanjai J. Parikh, UC Davis).

### *7. Grower Use*

At present there is a pressing demand for reliable information relevant to CA soils and cropping systems regarding the use of biochar. If biochar is shown to be beneficial for retaining or delivering nutrients to crops, providing water savings, or increasing soil health there will be direct benefits to growers. The data collected from this project will be relayed directly to the California Department of Food and Agriculture (CDFA) to assist in developing guidelines for the regulation and use of biochar as a soil amendment in CA. In addition, we are in communication with the Governor's Office of Planning and Research (OPR), Office of Business and Economic Development (GO-BIZ), and CAL FIRE and will share information with them for development of biochar policy if warranted by data. The data and interaction with policy makers will provide the much needed information and guidelines for growers in the state to make informed decisions regarding the use of biochar soil amendments.

### **D. Objectives**

The overarching objective is to provide baseline data specific to CA regarding the potential for biochar to provide benefits as a soil amendment for increasing nutrient retention, C sequestration and improving drought resilience for agriculture in CA's Central Valley. Specific project objectives are:

1. Characterize biochars produced from biomass locally available throughout California;
2. Evaluate the impact of biochar amendments on soil-water dynamics, fertilizer inputs, nutrient use efficiency (including leaching), carbon stocks, soil aggregation, and crop productivity;
3. Evaluate soil conditions and biochar parameters, including biochar and fertilizer application rates, which are most likely to lead to beneficial outcomes from biochar soil amendments; and
4. Create the California Biochar Initiative in order to provide a forum for growers, crop consultants, farm advisors, fertilizer producers, regulators, and other stakeholder groups to obtain clear and objective information regarding the use of biochar in California agriculture.

### **E. Work Plan and Methods**

The proposed project will utilize field plots and greenhouse bioassays. Approximately one-acre field plots will be established in Yolo and Fresno Counties, with tomato-corn and tomato-sorghum rotations under drip irrigation, respectively. These field scale plots will provide a realistic scenario to assess biochars impact on nutrient dynamics and crop production. Additionally, greenhouse bioassays will be conducted at UC Davis to examine additional experimental variables (i.e., soils, biochar, fertilizers), with a specific focus on nutrient retention and leaching (e.g.,  $\text{NO}_3^-$ ). As biochar feedstock and production parameters will have a significant impact on its performance and outcome as a soil amendment, full characterization and evaluation of the biochars, with different soils, will be conducted. We will work with our cooperators in Placer County, as well as biochar producers (All Power Labs, Corigin, Cool Planet) to generate biochars from unwanted forestry and orchard biomass wastes, as well as utilize other common and locally available CA feedstocks. Biochars pre-reacted with fertilizers will also be included in the experimental matrix. Project



experiments will also evaluate biochar and fertilizer application rates and impact on soil fertility parameters. This project will provide critical baseline data on potential benefits of biochar amendment for use in California agriculture. The three-year project will be conducted in a staged approach with results from early stages informing the research plan for later stages. This approach will allow for tailoring of biochar for increased potential agronomic benefit. The timeline for the proposed project is provided in Table 1.

Table 1. Proposed work plan.

Tasks and Other Activities	Year					
	1		2		3	
Task 1: Produce and characterize biochar	✓					
Task 2: Field trials in Yolo and Fresno Counties		✓	✓	✓	✓	✓
Task 3: Greenhouse Bioassays		✓	✓	✓	✓	✓
Task 4: Economic analysis of biochar amendments in CA.				✓	✓	✓
Task 5: Conduct an outreach program	✓	✓	✓	✓	✓	✓
Interim, Annual, and Final Reports to FREP		✓		✓		✓
Presentations to stakeholders and publication preparation				✓		✓

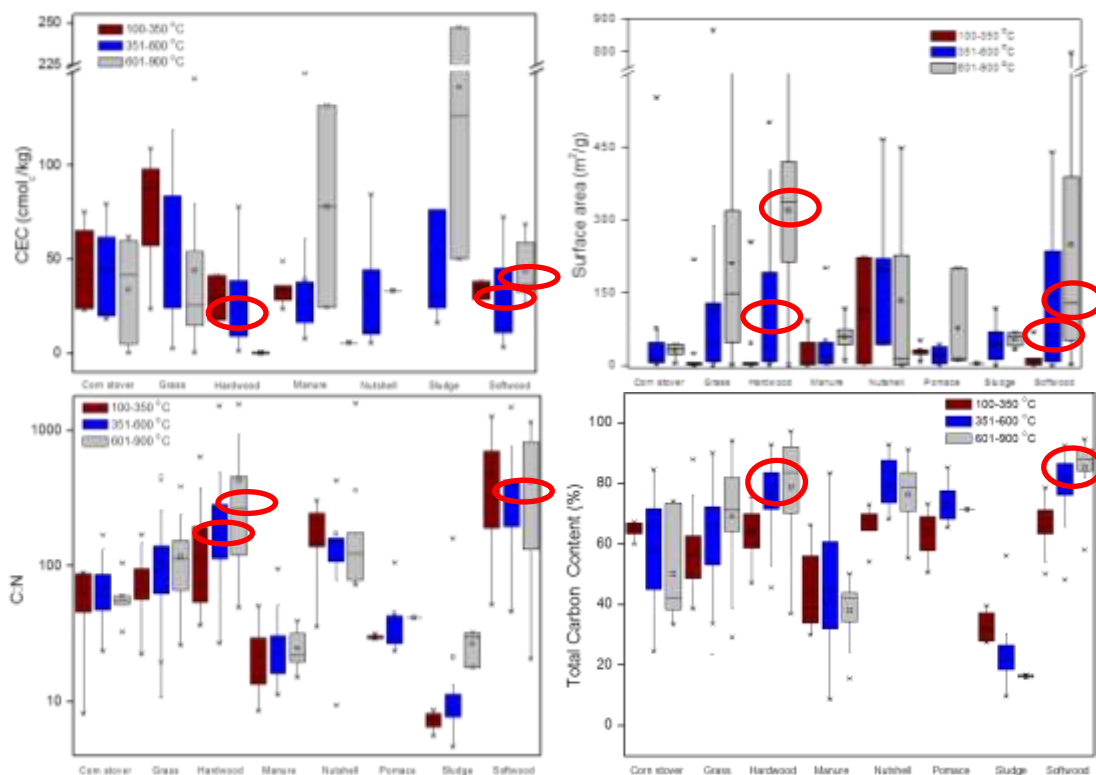
#### Task 1. Produce and characterize biochar.

Biochars will be produced from forest thinning materials from Placer County CA (field) as well as using other CA relevant biomass at 500 and 700 °C. Biochar will be produced by pyrolysis through collaboration with Corigin and Cool Planet and via gasification with All Power Labs. Complete characterization of the biochars will be performed in order to correlate results with specific chemical and physical properties of the chars. Biochar properties vary significantly based on feedstock material and temperature, but based on prior analysis known target values for specific properties have been identified (Fig. 1). All biochar samples will be analyzed for CEC using a modified (biochar) ammonium acetate method (Chapman, 1965) developed in the Parikh lab (Mukome, et al., 2013), pH (1:2 w/v) solution with and without 0.01 M CaCl<sub>2</sub>, total negative surface charge (Boehm Titration) and elemental composition (USEPA., 1996). Saturated paste extracts will be analyzed using inductively coupled plasma mass spectrometer (ICP-MS; Agilent Technologies 7500a). C, H and N will be measured simultaneously by total combustion (Costech ECS 4010). Particle size (Beckman-Coulter LS-230), moisture content, and ash content will also be determined. In addition, BET surface area measurements will be conducted (AUTOSORB-1, Quantachrome Instruments) and mineralogy/crystallinity will be determined using X-ray Diffraction (XRD) spectroscopy (Diano XRD 8000 diffractometer). Finally, attenuated total reflectance (ATR) FTIR spectroscopy (Thermo Nicolet 6700) (Keiluweit, et al., 2010, Novak, et al., 2010, Parikh, et al., 2014) will be used to examine contributions from aromatic and various functional groups (e.g., -COOH, -OH, -CH<sub>3</sub>) from the soil and biochar samples.

#### Task 2. Conduct field trials in Yolo and Fresno Counties

The main focus of the field experiments will be to elucidate the impacts of biochar amendments on agroecosystem functioning and to determine if, at the field-level, biochar has the potential to improve nutrient use efficiency, crop production, and plant available water. *A minimum of four biochars will be used in the field trials at two locations, with variation in application rate as well as fertilizer source and rate (i.e., N amount).* Additional variables will be evaluated in the companion greenhouse studies. Three-year field experiments will be conducted at the UC Davis Campbell Tract Facility (Davis, Yolo County) and the UC West Side Research and Extension

Center (Five Points, Fresno County). The treatment matrix for biochar and fertilizers in field trials is provided in Table 2.



**Figure 1.** Variation in important biochar properties as a function of feedstock material and temperature. Red circles are used to indicate expected values for hardwood and softwood biochars (biochar.ucdavis.edu).

Table 2. Treatment matrix for field plots in Yolo and Fresno Counties (rec. = recommended fertilizer rate).

Biochar	Temp. (°C)	Biochar Rate (% to 30 cm)	Fertilizer
Pine (forest thinning material)	500	0.5	synthetic drip (rec., low), pretreated biochar, digestate,
		1	synthetic drip (rec.)
Almond Shell (Corigin)	500	0.5	synthetic drip (rec, low), pretreated biochar, digestate,
		1	synthetic drip (rec.)
Pine (Cool Planet)	500	0.05	synthetic drip (rec.)
		0.5	synthetic drip (rec, low)
		1	synthetic drip (rec.)
Modified Pine (Cool Planet)	500	0.05	synthetic drip (rec.)
		0.5	synthetic drip (rec, low)
		1	synthetic drip (rec.)

A tomato-corn rotation will be grown in Yolo silt loam at Campbell Tract and a tomato-sorghum rotation in a Panoche clay loam at the West Side REC. These two soil series represent a combined total of 463,203 acres throughout CA (Figure 2). Controls with all fertilizer treatments and no biochar will also be included in the experimental design. Measurements will include soil chemistry (C, NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>, P, K, Mg, Ca, Na, pH, EC), crop quality and nutrition, soil water content, and microbial diversity (PLFA) as described below.

At each location, the experimental design will consist of a randomized block split-plot design (20 ft x 15 ft each) with four replications of each treatment. Although each plot will be 300 ft<sup>2</sup>, only the center 10 ft x 5 ft will be used for sampling of soil and plants, creating a 10 ft buffer zone around each sampling area in order to avoid edge effects between treatments. The biochar will be applied to the field following protocols we have previously developed. This will be done by applying biochar on a day with minimal wind following incorporation into the soil to a depth of 30 cm. All personnel applying biochar will wear hazmat suits and respirators to prevent breathing and skin contact with the dust. Biochars will be used at application rates 0, 0.05, 0.5, and 1% by mass in the top 30 cm as specified in the above table. This application rate roughly correlates to 1, 10, and 20 tons/ha. Soil samples will be collected to determine fertilization requirements and fertilizer will be applied via drip irrigation at the recommended N rate, and a reduced N rate, in order to evaluate biochars impact on nutrient use efficiency. An additional treatment of soft wood biochar pre- inoculated with fertilizer will be used to evaluate the impact of pre-loading N-P-K onto biochar before incorporation into soil.

Soil cores will be taken from each treatment block at least twice per year (preplant, post harvest). Soil cores will be collected at two depths (0-30 cm, 30-60 cm) in triplicate within each treatment blocks. Composite samples will be analyzed for extractable NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, K, Mg, Ca, Na, pH, salinity (via EC and SAR determination), CEC, and total C and N. Crop yield and quality assessments will be conducted by hand harvesting a subset (5' x 6') of each treatment block with dry weight biomass determined by drying a sub-sample of the total biomass at 60° C for 48 h or until constant weight is reached and scaling up to plot size. Plant samples will be analyzed for total macronutrient (N, P, K, Ca, Mg, S) and micronutrients (Fe, B, Mn, Cu, Zn, Mo, Cl). Intact soil cores will be collected both before and after each growing season and placed in Tempe cells to measure differences in plant available water holding capacity. To support plant available moisture measurements, soil moisture will be monitored during the growing season via gravimetric water content. Finally, the impacts of biochar addition on microbial communities will be examined using phospholipid fatty acid (PLFA) analysis for biomass determination and as a screening method for detecting microbial community changes. PLFA analysis will be performed on soil samples using previously reported methods (Bossio and Scow, 1998).

At the end of the study period water-stable aggregates from each treatment block will also be evaluated, using the wet-sieving method adapted from Elliott (1986), to examine the impact of biochar on soil aggregation – a key indicator of soil health. Briefly, soils will be sieved using an 8 mm sieve by gently breaking the soil clods by hand along the natural planes of weakness. This sample will then be successful passed through a series of sieves (2000 µm, 250 µm and 53 µm) to generate four aggregate size fractions: 1) > 2000 µm (large macroaggregates); 2) 250-2000 µm (small macroaggregates); 3) 53-250 µm (microaggregates); 4) < 53 µm (silt and clay fraction). Finally, the mean weight diameter (MWD) of soil aggregates will be determined.

#### Task 3. Greenhouse Bioassays

With the greenhouse bioassay we aim to meticulously investigate the effect of biochar and fertilizer additions on plant growth, nutrient retention and leaching (e.g., NO<sub>3</sub><sup>-</sup>), soil-water dynamics, and soil microbial diversity under controlled conditions. The greenhouse assays will link directly to the field through the use of corresponding treatments, but will also explore other soil types and biochars, which cannot be investigated in the field due to logistical constraints. The experimental design consists of pots arranged in a complete randomized block design. Treatments will include

the same biochars from the field trials with two additional biochars made from walnut shells and ponderosa pine (biochar n = 6, application rates of 0, 0.5, 1% by mass). As shown in Table 3 and Figure 2, in addition to Yolo and Panoche soils from the field sites two additional soil types will be used (Hanford, Tujunga), representing over 1 million acres of CA land surface. Based on soil analysis, all treatments will receive recommended N-P-K fertilizer rates for corn and tomato, respectively. In year 3, selections on promising biochar and soil types will be made to more fully evaluate different fertilization rates in conjunction with biochar amendment in greenhouse trials.



**Figure 2.** California map showing distribution of soil series (and CA acreage) which have been selected for the proposed project (Map and data from SoilWeb Apps, California Soil Resource Lab, UC Davis).

Table 3. Soil textural class and study components where selected soils will be used.

Soil Series	Textural Class	Study Component
Hanford	Fine Sandy Loam	Greenhouse
Panoche	Loam	Field, Greenhouse
Tujunga	Sandy Loam	Greenhouse
Yolo	Silt Loam	Field, Greenhouse

A continuous corn-tomato rotation will be grown in the pots that will be watered to maintain water content at field capacity. Any leachate will be collected weekly and be analyzed for  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , P, pH, C, and EC. For all pots, once the crops reach a harvestable stage, wet and dry yield measurements will be obtained. Water use efficiency or yield per unit of water from the different treatments will be determined. Plant samples will be analyzed for total macronutrient (N, P, K, Ca, Mg, S) and micronutrients (Fe, B, Mn, Cu, Zn, Mo, Cl). After harvest, the soil from each pot will be destructively sampled, sieved, air dried and analyzed for final physico-chemical analyses (total C,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , P, DOC, EC, pH,). All greenhouse related experiments and analyses will be performed in triplicate.

#### Task 4. Economic cost-benefit analysis of biochar amendments in CA.

An economic cost-benefit analysis will be conducted to determine the feasibility of biochar use in CA agriculture. The analysis will consider the cost of acquiring biochar and assess the risk vs. reward of utilizing biochar amendments for agronomic purposes, with a focus on fertilizer requirements. Fertilizer savings equivalents will be calculated according to fertilizer source, such as ammonium sulfate, calcium-ammonium-nitrate in a 17% formulation (CAN17), anhydrous ammonia, aqua ammonia, urea, and urea-ammonium-nitrate in a 32% formulation (UAN32). Fertilizer equivalents for each fertilizer are calculated on a per acre basis accounting for residual soil N and biochar amended fertilizers and converted into dollars per pound of N, averaged over 4 years according to data from the UC Davis Cost Studies (<http://coststudies.ucdavis.edu/>). These

potential fertilizer savings will be compared to the equivalent price of a maximum allowable yield loss. We will express the results over a range of values per ton of crop yields. Prices for crops will be calculated in current dollars using USDA data for CA, which will be used to establish the maximum allowable yield loss that could be sustained. A percentage yield loss will be used to normalize results across the various biochar and fertilizer treatments.

#### Task 5. Outreach Program

The Governor's Office of Planning and Research (OPR) has been looking at biochar as a way to sequester carbon and reduce agricultural water, fertilizer use, and environmental impact. One of the initial findings is that despite a lack of formal support, there is considerable interest in biochar throughout the state. That interest provides an opportunity to educate the public and agricultural professionals, as well as gather site specific information on biochar's effect on fertilizer, irrigation, and crop performance. We will create the California Biochar Initiative (CBI) to encourage and coordinate local efforts, collaborate with UC and CSU researchers and Cooperative Extension, community colleges, high school agricultural education programs, state and local agencies (CDFA, CARB, RCD's, etc.), grower groups, and the fertilizer industry to collect and disseminate information, give Continuing Education talks; prepare press releases, newsletter articles, and websites. We will use "The Biochar Blog", YouTube videos, online and regional conferences and training sessions to relay results of university and local experiments and determine effectiveness and potential of new applications. We view the buzz around biochar as a teachable moment for concepts in soil health, irrigation and fertilizer use, and the role of agriculture in recycling and other aspects of environmental stewardship. At the culmination of the project we will hold the first meeting of the CBI at UC Davis and share data from our project and on the state of biochar with interested stakeholder groups. It is anticipated that a minimum of 4 outreach activities will be conducted each year of the project.

### **F. Project management, Evaluation, and Outreach**

#### Management

Dr. Sanjai J. Parikh will serve as the project lead and will be responsible for all analytical procedures, field and lab work, data analysis, and project reporting. Dr. Parikh will co-advise one graduate student on the project with Dr. William R. Horwath. In addition, Dr. Horwath will be the co-lead for all field experiments and be the primary person on analysis of soil fertility. Dr. Michelle Leinfelder-Miles will provide expertise in agronomy and crop production and will be instrumental in working with Drs. Parikh and Horwath for developing protocols for field experiments and analysis. Dr. Kate M. Scow will be the primary lead on soil microbiology analysis and will oversee PLFA analysis. Dr. Anthony O'Geen will provide expertise on CA soils to assist in soil selection for field trials. Dr. Milt McGiffen will serve as lead for outreach activities and will assist on crop growth and analysis.

#### Evaluation

The use of biochar amendment to agricultural soils to increase fertilizer nutrient and water use efficiency in Yolo and Fresno Counties will be evaluated. We intend to utilize field, greenhouse, and laboratory experiments in order to provide realistic on-farm evaluations with field trials and broader screenings through laboratory incubations. The data will be used to develop relationships between biochar and fertilizer applications rates, soil carbon, soil texture, soil water content, nutrient leaching, and crop yields in order to generate much needed CA specific data for determining the efficacy of biochar soil amendment. In addition, we will evaluate the cost

effectiveness of biochar soil amendments to growers using locally sourced biomass for biochar production. Demonstration of conditions for increased nutrient use efficiency and/or drought tolerance for soils receiving biochar will provide growers and crop consultants with another powerful tool for farm management when developing nutrient management and irrigation plans.

#### Outreach

See Task 5 in Section E above.

### **G. Budget Narrative**

#### *a. Personnel Expenses: \$87,372*

Salary: \$83,738: Graduate Student Researcher III (TBN)

A graduate student co-advised by Parikh and Horwath will be the primary researcher on this project. The requested salary for Y1-Y3 is \$86,252 (Y1-Y3: 61%)

Benefits: \$1,120: Graduate Student Researcher VIII (TBN)

It is expected that the currently approved composite benefit rate of 1.3% for Graduate Student Researchers will remain in effect for the duration of the project.

#### *b. Operating Expenses: \$162,023*

Supplies and In-house Analysis: \$85,548: Funds are requested for in-house analysis to include total carbon and nitrogen (300 samples per year for Y1-Y3; \$9,180). Additional analysis of nitrogen speciation (nitrate, ammonia) and general soil fertility parameters (CEC, Ca, Mg, P, pH) will require \$13,050 (300 samples per year, Y1-Y3). Plant biomass will be analyzed nutrients, requiring \$10,032 (300 samples in Y1-Y3). For PLFA, at \$50/sample, \$6,000 is requested (Y1: 20 samples and Y2-Y3: 100 samples/year). The project will require \$3,000 in funding for greenhouse supplies for planting and irrigation. An abundance of general supplies such as chemicals, laboratory consumables (gloves, pipette tips, paper towels), solvents for analysis, and sample vials for this project will require funding (\$). Field trials will require significant funding for installation (i.e., drip installation, laser leveling), seed, fertilizer, and pesticide costs, and general farm management (Russel Ranch, Y1: \$11,441, Y2: \$6358, Y3: 6,987; West Side, Y1: \$9,500, Y2: \$5,000, Y3: \$5,000). Additional analysis and supplies not listed here will be covered using outside contributions to the project.

Travel: \$9,500: Travel has been budgeted for all project years to travel to field sites for setting up field experiments, transporting biomass for biochar production, routine measurement, and harvest in (Y1:\$4,500, Y2:\$2,500, and Y3: \$2,500). Travel costs include lodging (\$90/night), meals & incidental expenses (\$41/day), and transportation costs. In Y1 we anticipate a minimum of 10 trips by Project Leader Parikh and the graduate student for a total of 4,000 miles (10 nights in hotel and 20 days of food per person). In Y2-Y3 we anticipate 8 trips by the PI and graduate student for a total of 3,200 miles each year (with 8 nights in hotel and 16 days of food per person, per year). Outside funding will be used to supplement travel costs for both research and outreach related travel.

Other Expenses (Subject to Indirect): \$20,000: \$1,000 per year (\$3,000 total) in funding will be needed for greenhouse rental costs. Additionally, funding is requested to support outreach. This includes development of a web site for the California Biochar Initiative and videos for extending knowledge (\$15,000 for web developers and videographers). In Y3 a meeting of the California

Biochar Initiative will be held in Davis and will require \$2,000. These funds will be used to develop workshop materials (handouts) and cover logistical costs (e.g., IT, facilities, etc.).

Other Expenses (Not Subject to Indirect): \$46,975: As part of the employment of the TBN Graduate Student Researcher III receives the benefit of tuition and fee support. Utilizing Academic Year 2015/2016 rates as the base and assuming a 10% increase in each subsequent academic/fiscal year, funds totaling \$45,100 are requested to provide the tuition and support for the TBN GSR III with residency status. The final tuition and fee costs factor in a 25% credit reduction in relation to a program funded by the Provost Office. Additional funding (\$1,875) is requested to issue a sub award to UCANR for Dr. Michelle Leinfelder-Miles to travel to field sites and to UCD.

Indirect Costs: \$50,605: Per the agreement between the University of California and the State of California the indirect cost rate of 25.0% Modified Total Direct Cost (MTDC) has been used to calculate the associated indirect costs for the project.

*c. Other Funding Sources*

UC Davis: Dr. Parikh will commit 4% of his time over 3 years for total contribution of \$11,748 salary and \$4,476 benefits (total: \$15,954).

Placer County Air Pollution Control District, Erik White: The Placer County Air Pollution Control District will provide feedstocks for biochar, 60 hours of staff labor (\$6,000 value) to assess greenhouse gas impacts on project's production of biochar and use as soil amendment, and \$5,000 cash for project support. This financial support will be used cover salary for a to be named undergraduate research assistant.

Cool Planet, Drew Jackson: The biocarbon and bioenergy company, Cool Planet, will provide at least 500 kg of their Cool Terra product to be used in the proposed experiments. In addition, they will provide a donation to the project in the amount of \$30,000. This funding will cover analysis costs for plant and soil samples which have not been detailed above (additional 100 samples/year), as well as general lab supplies, and additional travel costs. Cool Planet is also interested in providing additional funding to extend the length of the project if an extension is warranted.

Corigin, Mike Woelk: The biochar company, Corigin, will provide 500 kg of two different pyrolyzed biochars and smaller quantities other biochar materials at no cost to the project. These materials will be used in field, greenhouse, and lab experiments.

All Power Labs, Tom Price: The biomass to energy company, All Power Labs, will provide 500 kg of two different gasified biochars at no cost to the project. These materials will be used in field, greenhouse, and lab experiments.

***References:***

See Appendix D.